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Appendix

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A Pseudocode of MNS Improvement Neighborhoods

```
Refresh Tabu List according to actual system time
Calculate decreasing cost ranking for als vehicle tours

WHILE (simulation_time < t_fixtime) {
      Identify feasible pair of vehicles for neighborhood operation, preferably a combination of a
      ‘‘cheap’’ and an ‘‘expensive’’ vehicle tour, taking into account the Tabu list
       -> vehicle_a and vehicle_b
      Determine the exchangeable requests for vehicle_a and vehicle_b
       -> exchangeable_req_a and exchangeable_req_b
      Calculate the initial cost for the tours of vehicle_a and vehicle_b
       -> initial_cost
      Set best_cost = 999 999 999; best_tourroute_a = NULL; best_tourroute_b = NULL

      FOR (i=0; i<exchangeable_req_a; i++) {
            FOR (j=0; j<exchangeable_req_b; j++) {
                  IF (request i is compatible with vehicle B && request j is compatible with vehicle A) {
                        Extract requests i and j from the tours of vehicle_a and vehicle_b, respectively
                        Apply Best-Reinsertion for request i into tour B
                        Apply Best-Reinsertion for request j into tour A
                        Calculate the new cost for the tours of vehicle_a and vehicle_b
                         -> new_cost
                        IF (new_cost < best_cost) {
                              best_cost = new_cost
                              best_tourroute_a = new tour of vehicle A
                              best_tourroute_b = new tour of vehicle B
                        }
                  }
            }
      }

      FOR (i=0; i<exchangeable_req_a; i++) {
            IF (request i is compatible with vehicle B) {
                  Extract request i from the tour of vehicle_a
                  Apply Best-Reinsertion for request i into tour B
                  Calculate the new cost for the tours of vehicle_a and vehicle_b
                   -> new_cost
                  IF (new_cost < best_cost) {
                        best_cost = new_cost
                        best_tourroute_a = new tour of vehicle A
                        best_tourroute_b = new tour of vehicle B
                  }
            }
      }

      FOR (j=0; j<exchangeable_req_b; j++) {
            IF (request j is compatible with vehicle A) {
                  Extract request j from the tour of vehicle_b
                  Apply Best-Reinsertion for request j into tour A
                  Calculate the new cost for the tours of vehicle_a and vehicle_b
                   -> new_cost
                  IF (new_cost < best_cost) {
                        best_cost = new_cost
                        best_tourroute_a = new tour of vehicle A
                        best_tourroute_b = new tour of vehicle B
                  }
            }
      }

      IF (best_cost < initial_cost) {
            Set tour of vehicle A = best_tourroute_a
            Set tour of vehicle B = best_tourroute_b
      }
}
```

Table 1: Pseudocode: λ-1 interchange (neighborhood I)

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```
Calculate decreasing cost ranking for all vehicle tours

WHILE (simulation_time < t_fixtime) {
      Choose a vehicle, according to decreasing cost ranking
        -> current_vehicle
      Determine the exchangeable requests for current_vehicle
        -> exchangeable_requests
      Calculate the initial cost for the tour of current_vehicle
        -> initial_cost
      Extract the exchangeable requests from the vehicle's tour
        -> extracted_tour
      Generate all sequence permutations for possible re-insertion of the exchangeable requests
        -> permutations
      Set best_cost = initial_cost; best_tourroute = initial_tourroute

      FOR (i=0; i<permutations; i++) {
            Apply Best-Reinsertion of exchangeable_requests into extracted_tour
            in the sequence of permutation i
              -> new_tour
            Calculate the cost for new_tour of current_vehicle
              -> new_cost
            IF (new_cost < best_cost) {
                  best_cost = new_cost
                  best_tourroute = new_tour
            }
      }

      Set tour of current_vehicle = best_tourroute
}
```

Table 2: Pseudocode: intraroute optimal sequence (neighborhood II)

```
Calculate the current plan's objective value
  -> initial_objective
Duplicate the current plan for back-up
  -> initial_solution
Calculate decreasing cost ranking for all vehicle tours
Initialize a list all_exchangeable_requests

WHILE (simulation_time < t_fixtime) {
      FOR (i=0; i<number_of_vehicles; i++) {
            Choose most expensive vehicle, according to decreasing cost ranking
              -> current_vehicle
            Determine exchangeable requests for current_vehicle
              -> exchangeable_requests
            Append exchangeable_requests to the list all_exchangeable_requests
            Extract exchangeable_requests from current_vehicle's tour
      }
      WHILE (size of all_exchangeable_requests > 0) {
            Remove first request of all_exchangeable_requests
              -> first_request
            Apply Best-Reinsertion for first_request over all vehicle tours
      }
      BREAK
}

IF (Re-Insertion of all extracted requests was successful) {
      Calculate the new plan's objective value
        -> new_objective
      IF (new_objective > initial_objective) {
            Reconstruct initial solution
      }
}
ELSE {
      Reconstruct initial_solution
}
```

Table 3: Pseudocode: complete solution rebuild (neighborhood III)

B Parameterization - Detailed Results

Appendix B contains the detailed planning results of the parameterization process in Section 5.5.1. The adapted MNS procedure is applied to the real-life test scenario.

	b	
a	empty travel time	delay
	break/wait	operating time

penalty cost "traveling empty"		penalty cost "delay" 1		5		8		10	
1		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
5		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
8		24133	221255	-	-	-	-	-	-
		465770	717746	-	-	-	-	-	-
10		23246	243138	-	-	-	-	-	-
		465497	716586	-	-	-	-	-	-
20		20281	350737	26135	139345	28174	118806	-	-
		467961	716086	484150	738128	487316	743333	-	-
30		-	-	24246	170913	26805	144508	27424	128188
		-	-	485496	737585	489000	743648	489660	744927
40		-	-	23355	195087	25364	161562	26278	143374
		-	-	485167	736366	488883	742091	490328	744449

Table 4: Parameterization of penalty costs (simulation speed s = 5, improvement neighborhoods I:II 66:33, anticipation horizon 10 min) - Detailed Results (in hours)

penalty cost "traveling empty"		penalty cost "delay" 1		5		8		10	
1		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
5		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
8		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
10		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
20		-	-	26157	136544	-	-	-	-
		-	-	486986	740986	-	-	-	-
30		-	-	24171	159541	26319	135305	27242	123891
		-	-	485833	737847	486831	740994	488387	743472
40		-	-	22969	193705	24817	150976	-	-
		-	-	484724	735536	487621	740281	-	-

Table 5: Parameterization of penalty costs (simulation speed s = 1, improvement neighborhoods I:II 66:33, anticipation horizon 10 min) - Detailed Results (in hours)

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		empty traveling	delay	break/wait	operating time
anticip. horiz.	5 min	24450	175323	485956	738249
	10 min	24246	170913	485496	737585
	30 min	24610	170142	488326	740780
	60 min	24545	173351	486564	738953
	90 min	24561	177846	485891	738295
	120 min	24591	187401	486199	738633

Table 6: Parameterization of anticipation horizon (simulation speed s = 5, improvement neighborhoods I:II 66:33, penalty costs (30,5)) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
anticip. horiz.	5 min	24193	162010	484880	736916
	10 min	24171	159541	485833	737847
	30 min	23966	158126	485019	736828
	60 min	23937	159509	485865	737646
	90 min	24076	168449	486213	738133
	120 min	24042	164628	485491	737377

Table 7: Parameterization of anticipation horizon (simulation speed s = 1, improvement neighborhoods I:II 66:33, penalty costs (30,5)) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
% I- % II	100-0	24455	164946	486402	738700
	75-25	24581	168246	488889	741313
	66-33	24246	170913	485496	737585
	50-50	24165	169027	487310	739317
	33-66	24579	177323	485439	737862
	25-75	24407	170408	486550	738800
	0-100	26193	220953	491455	745491

Table 8: Parameterization “allocation of improvement time” (simulation speed s = 5, anticipation horizon 10 min, penalty costs (30,5)) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
% I- % II	100-0	24008	154654	487019	738870
	75-25	24071	167129	486340	738254
	66-33	24171	159541	485833	737847
	50-50	24164	166108	484947	736955
	33-66	24081	161118	484747	736671
	25-75	24152	166242	485971	737966
	0-100	26055	214509	489198	743096

Table 9: Parameterization “allocation of improvement time” (simulation speed s = 1, anticipation horizon 10 min, penalty costs (30,5)) - Detailed Results (in hours)